

N 70-32745

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AUTOMATIC CALIBRATION SYSTEM FOR  
STRAIN-GAGE PRESSURE TRANSDUCERS

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1. Report No. NASA TM X-2045	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle AUTOMATIC CALIBRATION SYSTEM FOR STRAIN- GAGE PRESSURE TRANSDUCERS		5. Report Date July 1970	
		6. Performing Organization Code	
7. Author(s) Marvin W. Tiefermann		8. Performing Organization Report No. E-5647	
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 126-63	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract  This report describes an automatic pressure calibration system in operation at Lewis. Also presented is a typical testing program for complete evaluation of strain-gage pressure transducers. As many as 20 transducers can be calibrated at 75° F (297 K) in 7 min with pressure ranges from 1 to 2000 psi (0.7 to 1379 N/cm <sup>2</sup> ). The effects of temperature, overpressure, pressure cycling, and reference pressure (on differential transducers) can be measured and processed in a computer. System inaccuracy is less than 0.1 percent of full-scale output.			
17. Key Words (Suggested by Author(s)) Automatic system Pressure Strain-gage pressure transducer Calibration Temperature effects		18. Distribution Statement Unclassified - unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 10	22. Price* \$3.00

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Springfield, Virginia 22151

# AUTOMATIC CALIBRATION SYSTEM FOR STRAIN-GAGE

## PRESSURE TRANSDUCERS

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### SUMMARY

This report describes an automatic pressure calibration system and a typical testing program for complete evaluation of strain-gage pressure transducers. As many as 20 transducers can be calibrated at 75° F (297 K) in 7 minutes with pressure ranges from 1 to 2000 psi (0.7 to 1379 N/cm<sup>2</sup>). The effects of temperature, overpressure, pressure cycling, and reference pressure (on differential transducers) can be measured and processed in a computer. System inaccuracy is less than 0.1 percent of full-scale output.

### INTRODUCTION

A basic part of the instrumentation program of the Lewis Research Center is the determination of the characteristics of strain-gage pressure transducers. An automated central calibration facility has been installed to provide this capability. The functions of this facility are the following:

- (1) To provide calibrations for transducer users
- (2) To evaluate newly purchased transducers to insure that they meet purchase specifications
- (3) To generate data to allow statistical evaluation of the transducers. This provides information on the probable error of pressure measurements and indicates preferred sources of transducers.

A large number of measurements is required to evaluate a transducer, especially if calibration at various temperatures is included. The problem is even worse when large numbers of transducers are involved.

Each transducer has unique calibration "constants" and errors associated with it. The evaluation of a pressure transducer really amounts to determination of these "constants" and their stability with temperature, pressure, time, and usage at the Lewis

Research Center. The "constants" of interest are sensitivity and output with zero pressure since it is assumed that the device is linear. The errors then are nonlinearity and hysteresis which define variation from the assumed linear output. Additional errors are those which result in changes of sensitivity and zero output with temperature, overrange of pressure, and pressure cycling. Zero output and sensitivity may also change with application of a reference pressure to both sides of a differential pressure transducer. Other sources of error are temperature gradients across transducers and vibration and acceleration.

In the past all transducers have been calibrated at 75° F (297 K). Very few were calibrated at other temperatures. This amounted to 3500 calibrations per year or 40 000 data points. To evaluate all new transducers for the effects of temperature, overpressure, and line pressure required our calibration capacity to increase by a factor of about five. To meet these requirements, an automatic transducer calibration system has been developed and put into service at Lewis Research Center. The purpose of this report is to describe the system and the test programs being run to evaluate transducers. A typical test program for a gage-type transducer and a sample of computed results are included. Tests on the effects of temperature gradients, vibration, and acceleration are not included in these programs.

The system was designed to test large numbers of transducers with a minimum of manual operations. Twenty pressure transducers can be calibrated at a time at any temperature from -50° to 250° F (228 to 394 K). Full-scale range of the transducers can be from 1 to 2000 psi (0.7 to 1379 N/cm<sup>2</sup>). Calibrations can also be made before and after pressure cycling and before and after overpressure. Data are taken with an automatic data system (ref. 1). The raw data are processed in a computer to determine nonlinearity, hysteresis, zero unbalance, sensitivity, and shunt calibration resistor. These characteristics can then be compared for changes with temperature, exercise, or overpressure. The errors in determining the aforementioned characteristics are less than 0.1 percent of full scale.

## DESCRIPTION OF SYSTEM

This system can be divided into four main sections as follows:

- (1) A table on which the transducers are connected to a common manifold. This table also serves as an environmental chamber.
- (2) A working standard to measure accurately the pressure applied to the transducers
- (3) An automatic data system
- (4) A system which controls the test sequence, transducer temperature, applied pressure, and so forth

Figure 1 shows a group of differential pressure transducers connected to a common manifold on a table. The system has three tables for testing low-, medium-, and high-pressure transducers. There are 18 different ranges from 1 to 2000 psi (0.7 to 1379 N/cm<sup>2</sup>) as shown in the following table:

Range of pressures for testing various transducers, psi (N/cm <sup>2</sup> )		
Low	Medium	High
1, 2, 5, 10, and 15 (0.7, 1.4, 3.4, 6.9, and 10)	25, 30, 50, and 100 (17, 21, 34, and 69)	150, 200, 250, 300, 500, 750, 1000, 1500, and 2000 (103, 138, 172, 207, 345, 517, 689, 1034, and 1379)

Only one table can be run at a time but technicians can be connecting or disconnecting transducers to the other two while one is running.

Each table has two pressure manifolds such that unidirectional or bidirectional differential transducers can be calibrated as well as gage or absolute units. The two manifolds are also used to check the amount of zero shift with equal pressure on both sides of differential transducers (reference pressure).

The manifolds are connected to a pressure standard, pressure regulators, gages, solenoid valves, vacuum pumps, and a 2500-psi (1724-N/cm<sup>2</sup>) source of dry nitrogen gas as shown in figure 2.

Calibrations at any temperature between -50° and 250° F (228 and 394 K) can be run without moving the transducers. An insulated hood shown suspended above the table in figure 1 can be lowered onto the table and clamped in position making each table an environmental chamber. Air is circulated over the transducers and back through a duct in the bottom of the table. In this bottom duct there is a blower, an electrical heater, and a liquid nitrogen cooling coil. The temperature of the transducers can be changed 50° F (28 K) in 15 minutes.

The pressure working standard is the combination of a force balance transducer and servoamplifier which has an analog output voltage. The working standard was chosen because of its wide pressure range, its accuracy, and its capability to be used for both gage and absolute calibrations. Also, dry nitrogen gas can be used as the working fluid

which eliminates transducer cleaning after calibration except for critical service such as oxygen.

Seven force balance transducers are used to cover all 18 ranges. Resolution of the standard is 0.01 percent of full-scale range and the limit of error is 0.05 percent of full-scale range. Although the transducers are down ranged, the error is limited to 0.05 percent in the following manner:

- (1) The transducers are located in constant temperature ovens to minimize errors due to temperature changes.

- (2) All ranges are periodically calibrated with a dead weight piston gage.

- (3) For every pressure to be measured, the analog output of the working standard is read eight times with an integrating voltmeter. These readings are averaged to minimize errors due to acceleration or vibration.

A digital data acquisition system is used to record all information. This data system consists of local digitizers and one remote central control and recorder. The information recorded includes the excitation and output voltages of the transducer, the transducer temperature, and the pressure standard output. The system records data at a rate of 30 words per second with a limit of error of 0.03 percent of full scale. The data are recorded on magnetic tape and held for batch processing in the computer. The raw data from each run can also be played back on a typewriter to aid the system operator in checking for malfunctions. The data system also reads out an identification number for each transducer. These numbers are manually set with thumbwheel switches prior to testing.

A drum programmer is used to program the test sequence order to the transducers. The drum has three separate programs, one for each of the three types of transducers-gage, absolute, and differential. This drum is the heart of the system control. It controls solenoid valves; calls the data system; calls for auxiliary programs; and determines when tests are performed such as overpressure, line pressure tests on differential transducers, and evacuation tests on gage units. In addition, there are the following four auxiliary fixed programs:

- (1) Pressure Calibration - This steps the pressure to the transducers in approximately 10 percent increments from zero to full scale and back to zero for a 21-step calibration. The steps are not exact increments but are measured accurately. No data is taken at any pressure until equilibrium is achieved. This is done by monitoring the output of the pressure standard with a digital voltmeter (DVM). This output must remain constant for a preset period of time before data are taken. The total time for the 21-step calibration of 20 transducers is 4 minutes.

- (2) Shunt Calibration Program - This program shunts 20 different precision resistors across one arm of each transducer at zero pressure. From this data the shunt calibration resistor that simulates full-scale output is automatically calculated.

(3) Temperature Program - This program sequentially changes transducer temperatures so that calibrations at desired temperatures are obtained. Any seven of nine preselected temperatures may be chosen with a selector switch prior to testing. The nine preselected temperatures may range from  $-50^{\circ}$  to  $250^{\circ}$  F (228 to 394 K) and are determined by the settings of potentiometers.

(4) Exercise Program - This cycles the transducers from zero to full-scale pressure and back to zero.

The transducer signal conditioning consists of 60 individual power supplies. Although only 20 transducers can be calibrated at one time, the other supplies can be used to warm up transducers connected to another table prior to testing. The supplies are individually adjustable from 1 to 16 volts. Four shielded and twisted pairs of wire are used to connect a conditioner to a transducer. They are used for the transducer excitation, transducer output, sensing voltage, and shunt calibrating resistors. The sensing voltage pair is also used to measure the supply voltage at the transducer.

## SYSTEM OPERATION

Figure 2 is a simplified block diagram of the system. An operator connects like type and range transducers to the pressure manifold and switches in the proper range, type, and identification numbers. He then selects the temperature ranges to be covered, adjusts the source pressure to approximately 10 percent above the maximum pressure required, and pushes the start button. The control calls the data system which reads the transducer output from the signal conditioners and the pressure standard output at zero applied pressure. The data system signals to the system control when it is finished with that data point. Pressure is then increased automatically to 10 percent of full scale through solenoid valve 1. A digital voltmeter looks at the output of the pressure standard and determines when the pressure is stable. After pressure stability is reached, the data system is called again to read out the data for 10 percent of full scale. The data system signals when it is finished taking data and the pressure is increased to 20 percent of full scale. This sequence is repeated to full scale. Pressure is decreased in the same type of steps through solenoid valve 2. After a calibration, the raw data can be played back through the typewriter for a quick look to see if the calibration is good. The system control will then condition the transducers before the next calibration. This could be a change in temperature or overpressure, and so forth.

## TEST PROGRAM

Table I is a complete program for gage transducers. The first program step is a



pressure calibration, zero pressure to full scale and back to zero. From this calibration we determine the nonlinearity, hysteresis, zero unbalance, and sensitivity of the transducer. After every pressure calibration, the system goes through the shunt calibration program.

In program step 2 the transducer is exercised a number of times from zero to full scale and back to zero. The third step is another calibration. No data is taken during the pressure cycling but the calibration curves before and after cycling are compared for changes in zero unbalance and sensitivity. These changes indicate the nonrepeatability of the transducer.

In step 4 the transducers are overranged from two to ten times full scale depending on the specifications. No data is taken during step 4 but the calibrations before and after are compared for changes in zero unbalance, sensitivity, and nonlinearity.

Program steps 5 to 12 are a series of calibrations at selected temperatures. The first 75° F (297 K) calibration is used as a reference for all the remaining runs. Changes in sensitivity and zero unbalance are found for  $\pm 30^{\circ}$  and  $\pm 100^{\circ}$  F ( $\pm 17$  to  $\pm 56$  K) from the reference temperature. Thermal hysteresis (the nonrepeatability of transducers at 75° F (297 K) compared before and after they are heated or cooled) is also found with this series of tests.

In step 13 the transducers are evacuated to  $5 \times 10^{-2}$  torr and the calibrations again compared before and after evacuation. This test is designed to duplicate treatment of transducers in cleaning and as they are often used in the field.

Programs for absolute and differential transducers are similar to the gage transducer program. However, no evacuation test is needed for absolute units and the differential units have a series of tests to determine the amount of zero shift with line pressures from  $5 \times 10^{-2}$  torr to 2000 psig ( $1379 \text{ N/cm}^2$ ).

After a program is completed on a series of transducers, the raw data which are recorded on magnetic tape are batch processed in the computer.

Table II is a typical printout of computed data from a gage-type transducer. The first row is transducer identification data. In the second, third, fourth, and fifth rows are the computed characteristics of the transducer at 75° F (297 K). In the fourth row the nonrepeatability is defined as the square root of the sum of the squares of the changes in sensitivity and zero unbalance for calibrations taken before and after pressure cycling. Overpressure is defined the same as repeatability except that the changes in sensitivity and zero unbalance are due to the transducer being overranged. The evacuation zero shift term is the zero shift due to cycling the transducer from 1 atmosphere to  $5 \times 10^{-2}$  torr and back to 1 atmosphere. The bottom half of table II is the computed data from the temperature calibrations. The second and third columns contain the differences between the test temperature and the reference temperature, 75° F (297 K). Columns four and five are the sensitivity shift and zero shift due to the temperature change in columns two and three.



## CONCLUSIONS

Lewis Research Center has in operation an automatic calibration system to evaluate strain-gage pressure transducers. Data are processed in a computer and then used in the following manner:

1. To evaluate new transducers to see that they meet purchase specifications.
2. To provide a central calibration facility for new and used transducers at Lewis Research Center.
3. To provide statistical data on new transducer trends as well as comparing calibrations of used transducers with previous calibrations.

Lewis Research Center,  
National Aeronautics and Space Administration,  
Cleveland, Ohio, May 8, 1970,  
126-63.

## REFERENCE

1. Mealey, Charles; and Kee, Leslie: A Computer-Controlled Central Digital Data Acquisition System. NASA TN D-3904, 1967.

TABLE I. - TYPICAL TEST PROGRAM FOR  
GAGE TRANSDUCERS

Program step	Operation	Test temperature	
		<sup>o</sup> F	K
1	21-Step calibration	75	297
2	Exercise <sup>a</sup>	↓	↓
3	21-Step calibration		
4	Overpressure <sup>a</sup>		
5	21-Step calibration	↓	↓
6		45	281
7		105	314
8		75	297
9		-25	242
10		75	297
11		175	353
12		75	297
13	Evacuate <sup>a</sup>	75	297
14	21-Step calibration	75	297

<sup>a</sup>No data taken.

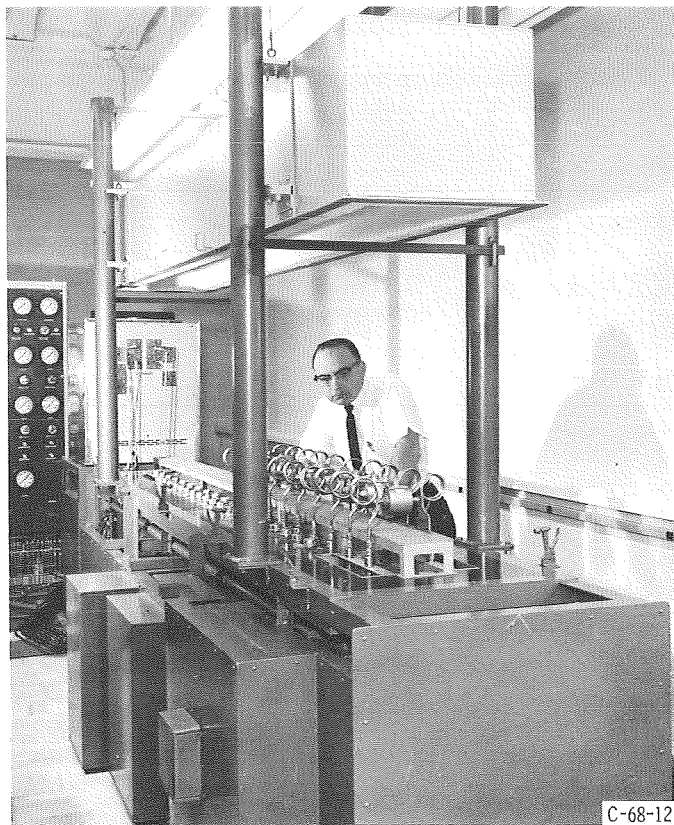
TABLE II. - COMPUTED DATA FROM A GAGE TRANSDUCER<sup>a</sup>

I. D. No. 40776    Type Gage    Range 300 psi (207 N/cm<sup>2</sup>)

Zero unbalance = 0.4, hysteresis = 0.15, nonlinearity = 0.25, shunt resistor = 24 206 ohms, sensitivity = 3.003 mV/V × full-scale pressure, excitation voltage = 10.0 V, nonrepeatability = 0.05, overpressure = 0.20, evacuation zero shift = 0.10

Temperature run number	Temperature difference		Sensitivity shift	Zero shift
	<sup>o</sup> F	K		
1	-30	-17	-0.28	-0.16
2	30	17	.20	.66
3	0	0	-.03	.49
4	-100	-56	.64	.56
5	0	0	-.06	1.72
6	100	56	-.09	-.22
7	0	0	.51	.15

<sup>a</sup>All data in percent of full-scale output unless otherwise marked.



C-68-121

Figure 1. - Pressure calibration table.

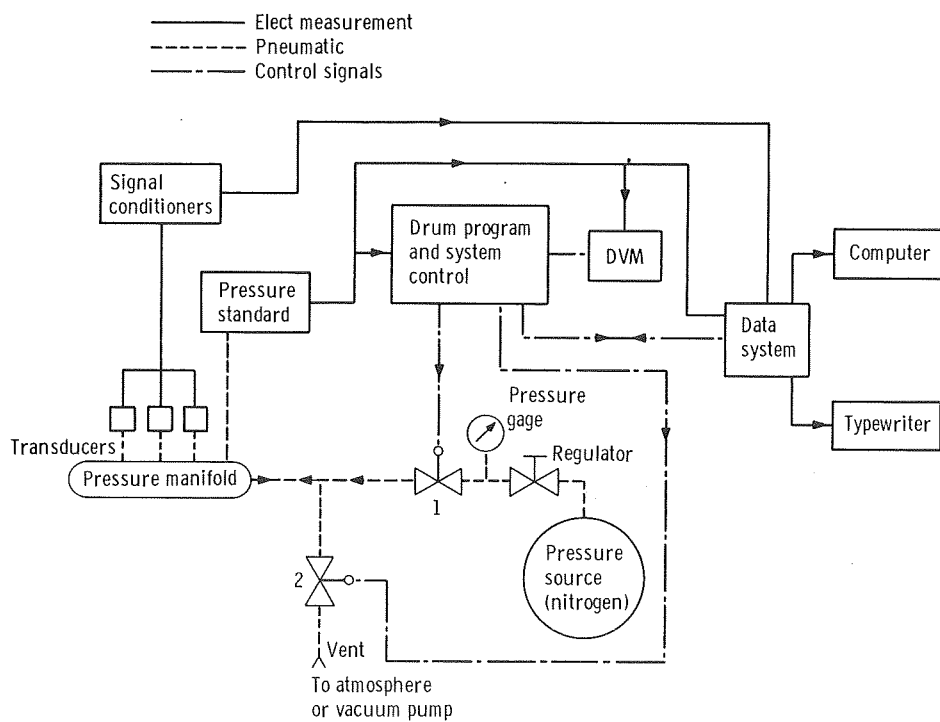
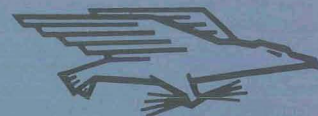


Figure 2. - Calibration system.

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